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REPORT ON THE FEASIBILITY OF USING PHENOCLIMATOGRAPHY MODELS TO PREDICT RANGE DEVELOPMENT AND PRODUCTION ON BLM WINTER RANGES

by

E. ARLO RICHARDSON

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INTRODUCTION

Nearly 250 years ago Réaumur (1735) recognized that the development of most plants, animals and insects was affected by various environmental factors such as soil characteristics, nutrient levels and atmospheric variables. There is an optimum set of these environmental factors specific for each living organism which will produce the maximum rate of development. The important environmental factors for plants include such elements of climate as temperature, humidity, rainfall, wind and sunshine. Other factors such as soil nutrient levels, diseases, insects, interspecies competition, day length, etc. futher complicate the situation.

If we consider each specific factor separately, by assuming that all of the factors except the one under consideration are near optimum for the organism and thus not limiting to growth and/or development and/or activity, we can define certain critical values of the variable which can be related to the development and/or activity (Fig. 1). In the

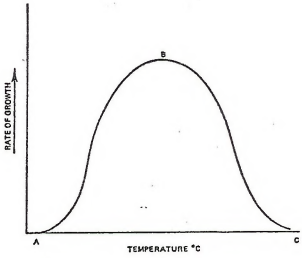

Figure 1

figure, A is the lower limit of the variable below which no appreciable growth or activity is in evidence, B is the optimum value at which the maximum rate of development or activity occurs and C is the upper limit beyond which death or damage to the organism occurs. The shape of the development curve will vary depending on the specific variable under consideration and the organism in question.

TEMPERATURE RELATIONSHIPS/PLANT/INSECT

During the last hundred years beginning with Fritsch (1861) and Abbe (1905) considerable effort has been made by researchers in relating environmental temperatures to plant development. J. Y. Wang (1963) reviewed some of the many approaches that have been reported in the literature. One of the more frequently used ideas, probably due to its simplicity, assumes that, within a range of environmental temperatures commonly found in nature, plant growth and/or development can be related to temperature quite satisfactorily by a straight line, for example an extension of the line AD in Fig. 2. The accumulation of energy represented by this line has been given several names: heat units (HU), energy units (EU) or growing degree days (GDD) being among the most common. This relationship assumes that regardless of how high the temperature may rise the rate of development increases linearly with increasing temperature. The accumulation of GDD units for any given 24 hour period is obtained

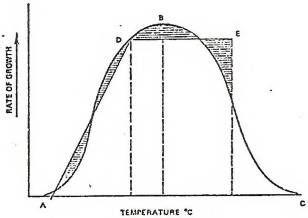

Figure 2

by subtracting a base temperature represented by TA for the specific plant species from the Average Temperature for the 24 hour period.

More recently the growth curve has been approximated by two straight lines AD and DE (fig. 2) where DE represents an average of the higher temperatures commonly observed. This method of accumulating energy units assumes that at temperatures above the values TD the rate of development remains constant. These GDD energy units are calculated by addition of the maximum temperature for the day and the minimum temperature and dividing the sum by two to obtain an average but if the maximum temperature exceeds TD then the maximum temperature is set equal to TD and if the minimum is less than TA it is set equal to TA. The average thus calculated is then used in the same manner as described in the first method of sumation. Comparisons of the two methods at Davis, California indicate that the predictive accuracy for the date of the first bloom of tomatoes is improved by about a half a day using the second method of calculation. Using the same constants in differing climates, the improvement is considerably greater. (Richardson et al. 1980)

In their 1980 study, Richardson et al. compared the accuracy of several methods of relating the temperature environment to the growth and development of tomatoes. A data set for tomatoes developed by Dr. Floyd Ashton of Davis, California which consisted of seven plantings with 9 plants in each planting was used to test the models.

The models tested were the two previously discussed plus two curvelinear models which represent versions of the curve in figure 1. The authors proposed a cosine equation in the form of equation 1.

$$GDH = \frac{FA}{2} \{1 + \cos [\pi + \pi (\frac{TH - TB}{TU - TB})]\} \qquad (1)$$

Where:

GDH = the accumulation of growing degree hours during an hour when:

TH = hourly temperature

TB = the base temperature below which no appreciable growth will occur. This corresponds to point A on the curve in Figure 1

TU = the optimum temperature or the temperature at which the maximum rate of growth will occur and corresponds to point B on the curve in Figure 1

TC = the critical temperature or the temperature beyond which little or no growth will occur and above which irreversible damage may be done to the plant or organism.

A = TU - TB (the amplitude of the growth curve)

F = A stress factor which can be used to represent any form of plant stress such as atmospheric stress from low humidity, soil moisture stress, stress from disease, insect damage or lack of nutrients.

A review of the response of several plant species to their environmental temperatures indicated that rather than following the true cosine curve to TC, the rate of response to increasing temperature decreased more rapidly above the optimum temperature than the rate of increase with increasing temperature below the optimum. Leavitt (1980). Also hypothesises a similar response in his curve on page 361.

A second response equation (2) was developed to account for this change in the response curve.

$$GDH = FA \{ 1 + \cos [\frac{\pi}{2} + \frac{\pi}{2} (\frac{TH - TU}{TC - TU})]\} \qquad (2)$$

If the value of TH is less than TU, then equation 1 is used in the accumulation of GDH; if the value of TH is greater than TU, then equation 2 is used.

Testing the four methods of calculating GDD or GDH on the tomato data set showed a marked improvement in the predictability when using the

combination of equations 1 and 2. The average difference between the predicted and observed dates of first bloom ranged from 4.27 days using the original linear response to only 1.81 using the combination.

TABLE 1

Comparison of predicted and observed dates of first bloom of seven plantings of tomatoes at Davis, California as calculated from four different models

Cardinal Temperatures			Average difference between Predicted and Observed Dates of First Bloom of Tomatoes
TB	TU	TC	
10°C	----	----	4.27 days
10°C	30°C	----	4.02 days
10°C	30°C	50°C	3.65 days
10°C	26°C	36°C	1.81 days

Where: TB = the base temperature
TU = the optimum temperature
TC = the critical temperature
all as defined in the text.

Similar increases in the accuracy of prediction of phenological stage of several native weed species competitive with tomato were found. It, therefore, appears reasonable that if the cardinal temperatures for the desired range species can be determined; the use of the model which combines equation 1 and 2 will produce considerable increase in accuracy.

PHENOCLIMATOGRAPHY MODEL FOR SUMMER RANGES IN UTAH

Under a grant from the U.S. Forest Service, Dr. W. A. Dugas, Jr. (1980) developed a model to predict range plant development and production using Equation 1. This model was developed and tested using data from the Ephraim and Straight Canyon Watersheds in Central Utah. These ranges are all high elevation summer ranges and the percent of plant cover is usually much higher than is found on the lower elevation BLM winter ranges in the

central portion of the state.

The objective of this study was to develop mathematical equations to predict range development and production utilizing only the weather variables commonly measured at National Weather Service climate stations. These variables are: daily maximum and minimum temperature, precipitation and snowfall. The hourly temperatures required by equation 1 were generated from a linear interpolation of successive daily maximum and minimum values (Richardson et al, 1974 and Heuer et al, 1978). This method assumes that the daily maximum and minimum temperatures occur 12 hours apart each day. The hourly temperatures for the first 12 hours of any day are calculated from equation 3.

$$TH_n = TNi - (n - 1)(TX_i - TN_i) / 11 \quad (3)$$

for values of n = 1 to n = 12. i = the day number of the period for which calculations are being made. Values of TH_n for the second 12 hours of the day are calculated from equation 4.

$$TH_n = TXi - (n-1)(TX_i - TN_{i+1}) / 11 \quad (4)$$

again for values of n = 1 to n = 12.

Empirical relations were used to determine the soil moisture compensation factor (F_m) Dugas (1980). The daily soil moisture budgetary procedure

$$ST_i = P_i - ET_i + ST_{i-1} \quad (5)$$

where ST is the storage of water within the soil profile (equivalent depth), P the precipitation and ET the actual evapotranspiration for day (i). Measurements or estimates of initial ST, daily values of P and ET, and the wilting point and field capacity values for the soil at each site are required.

Daily potential evapotranspiration (ETP was calculated from the

method of Blaney and Criddle (1962) and actual evapotranspiration (ET) from the method of Hanks (1974). Initially; ETP was separated into potential evaporation (EP) and Transpiration (TP) by an empirical relationship dependent upon the crop growth throughout the season. The specific equations used in the summer range program are as follows:

Calculation of Potential Evapotranspiration (modified Blaney-Criddle)(ETP_i):

$$ETP_i = \frac{\left(\frac{TX_i + TN_i}{2}\right) PDm}{100\ [\ ND\ ]} \tag{6}$$

Calculation of Potential Evaporation (EP_i):

$$EP_i = [\ CO_1 + CO_2\ (\frac{Today}{NDGS}) + CO_3\ (\frac{Today}{NDGS})^2 + CO_4\ (\frac{Today}{NDGS})^3 + CO_5\ (\frac{Today}{NDGS})^4\ ]\ [\ \frac{ETP_i}{100}\ ] \tag{7}$$

Where: PDm = Percent of daylight hours

ND = Number of days in the month

CO_n for n = 1 to 5 = Constants for estimating potential evaporation bond on Hank's model

Today = Todays day number of growing season

NDGS = Number of days in growing season at site

Calculation of Potential Transpiration (TP_i):

$$TP_i = ETP_i - EP_i \tag{8}$$

Calculation of Actual Evaporation (EA_i):

$$EA_i = EP_i\ (\frac{1}{N\ Days})^{1/2} \tag{9}$$

Calculation of Actual Transpiration (TA_i):

$$TA_i = TP_i \cdot AW \cdot 2 \tag{10}$$

if $(TA_i > TP_i)$ $TA_i = TP_i$

Calculation of Actual Evapotranspiration (ETA_i):

$$ETA_i = TA_i = EA_i \quad (11)$$

Where: N Days = number of days since last precipitation totaling .20 inches or more.

Calculation of Present Soil Moisture (PSM):

$$PSM = BSM - ETA + SP \quad (12)$$

if PSM > FC PSM = FC

if PSM < WP PSM = WP

Where BSM = Soil moisture of previous day

SP = Daily precipitation

Calculation of Percent of Water Available (AW):

$$AW = 1 = (FC - PSM) / (FC - WP) \quad (13)$$

Calculation of the Value of Compensation Factor (Fs)

$$Fs = y + [(1 - y) / cw\ ]\ AWi \quad (14)$$

Where y = Potential minimum value of Fs

and cw = Critical percentage of soil moisture below which the plant is subject to moisture stress

For the summer ranges Dugas estimates the values of:

y = 0.5 and
cw = .25

WINTER RANGE MODELS

Weather conditions on the winter ranges of the BLM are quite different from those found on the higher elevation summer ranges. Further, the plants commonly found on these two ranges differ appreciably in their production capabilities and their ability to withstand such stresses of weather extremes as drought and high temperatures.

Again the major objective of this study was to determine the

feasibility of developing mathematical models to predict range development and production utilizing only the more common meteorological elements measured at National Weather Service Climate stations.

The studies on tomatoes and competing weeds briefly reviewed previously indicated a potential for marked improvement in the predictive capabilities of the models if a combination of the two equations, 1 and 2, were used in place of the single equation used in the summer range model.

To properly utilize these equations, information on the three cardinal temperatures for each species is required. Since such information was not available, a thorough search of the relevant literature was first made to obtain the best estimate of these temperatures and information on other factors which influence the growth and development of the desired species. A brief review of the results of this literature search follows:

LITERATURE REVIEW ON THE SELECTED SPECIES

Atriplex canescens--Four Wing Salt Bush (Springfield, 1963)

Atriplex canescens is one of the most palatable of our southwestern shrubs. The leaves, stems and fruits are cropped by almost all classes of livestock. The plant has a deep root system. Mature plants will reach depths of 5 to 15 meters in alluvial soils. Its extensive root system makes the plant remarkably drought resistant. (Van Dersal 1938)

Afterripening

Seeds of four wing salt bush apparently undergo afterripening. This process involves chemical changes that remove germination blocks. Seeds of many species are dormant at the time of maturity. Four wing salt bush seeds frequently germinate better the second or third year after collection. From the description of the afterripening process, it is

possible a chilling requirement may be necessary; but Springfield (1963) does not seem to think so.

Germination

The uptake of water, imbibition, is the first process that occurs during germination. Studies indicate that 15 to 24 hours soaking in water is required to complete this process after which, if environmental factors are correct, germination continues.

Temperature effects

Four wing salt bush usually germinates best at relatively low temperatures. The woody plant seed manual (Forest Service 1948) recommends 77°F day and 50°F night temperatures for 20 to 30 days to test germination of the seed. Hervy (1955) obtained 47% germination of four wing salt bush at 68°F, 45% at 59°F and 77% at 39°F.

Hilaria jamesii--Galleta Grass (West et al 1972)

Galleta grass is a normally course perennial grass varying in height from 8 to 65 cm (3 to 20 inches). One of the most characteristic features of the species is its tough, woody rhyzomes which represent the plant's surest means of reproduction. Most roots and rhyzomes are found above 50 cm (18 inches) in the soil. Roots commonly extend up to 40 cm beyond the crown in all directions.

Germination

Galleta seed collected from various areas in the west germinated 85% or higher at temperatures ranging from 16 to 32°C (60-90°F).

Vegetative Growth

A study by Jameson (1965) showed that galleta maintained a green leaf height greater than about 5 cm (2 inches) from April 20 to November 1 in northern Arizona. The plants reached a summer growth plateau at a height

of 12 to 13 cm (4.5-5.5 inches) and reached an average peak height of 38 cm (15 inches) about September 11.

Jameson also reported that the early summer decline in growth rate, beginning of the summer growth plateau varied with elevation and probably with temperature. He concluded that the time of growth corresponded closely to the seasonal precipitation pattern, but earlier than normal precipitation did not result in earlier than normal growth of a warm season grass like galleta. (Warm season disagrees with later information reported on cardinal temperatures in the same bulletin which are: TB = 4°C, TU = 26°C and TC = 40°C.

The grass undergoes fall regrowth with adequate rainfall after the summer dormancy which appears to be drought induced. When adequate moisture is available during the late summer growing season, growth continues throughout the season.

The time of seed formation varies considerably. In dryer areas, the plants will produce seed and become dormant a full month before they do in more normal environments. Growth initiation and vegetative production appears to be temperature related, but flowering appears to be day length triggered. Growth initiation appears to be associated with average maximum temperatures in the air of 16°C (60°F). The species can withstand high temperatures and a desicating environment. The first seed heads formed in Tucson on March 24, 1970, but in the greenhouse and fields generally seed formation ranges between June and October. Thus the species evidently has some latitude in terms of daylength to trigger seed formation. It appears to flower whenever and as long as adequate moisture is available. The lethal temperatures are near 61°C (142°F).

Oryzopsis hymenoides--Indian Rice Grass

Oryzopsis growth and production appears to be determined more by spring moisture and temperature conditions than the winter moisture. (Fletcher and Trlica 1980). Regrowth has been observed after late season rainfall (Cook 1977). Growth usually begins in the latter part of March or in early April provided soil, moisture and weather conditions are favorable. In dry summers, plant growth stops, the herbage becomes dry and brittle; and frequently, the plants fail to produce flowers and seed. (Hutchings and Stewart 1953).

Phenology (Pearson 1979)

Observations of Indian Ricegrass indicate that the plant goes through four distinct phenological stages:

1. Sprouting in spring as dormancy is broken
2. Vegetative growth stage
3. Anthesis and maturation
4. Dormancy stage

Growth begins when the soil temperatures at the 15 cm depth warm up to 4°C and remain for at least 3 or 4 days. During the sprouting stage, foliage production appears to be essentially linear. Maximum plant height was also correlated with soil temperature.

Irrigation increased the amount of foliage produced and delayed the time of reaching the maximum leaf length.

Stipa Comata--Needle and Thread Grass

Stipa comata was to have been the fourth species studied but adequate information was not available either from the literature or from the BLM plant surveys. Crested wheat grass was, therefore, substituted. By the time the decision to change species was made,

there was not time to make as complete a literature survey as we would have liked.

Agropyron cristatum or desetorium--Crested Wheat Grass

Crested wheat grass begins growth early in the spring, but the wheat grasses are not as palitable to sheep as Bromus. It is one of the first grasses to start growth in the spring and continues to furnish pasture until late in the fall when moisture conditions are favorable. Ordinarily the poorest growth is made during the hot, dry periods in midsummer. For revegetation, the seed should be sown as early in the spring as possible (Wilson 1931)

Germination

Good germination occurred with temperatures of 20°C and 30°C, but the highest rate of germination was 20°C. The seeds can germinate under fairly high moisture stress if the temperatures are optional. McGinniess(1960)

Phenology

Dr. Fred Provenza (1980) of the USU range department who is working with crested wheat grass west of Eureka, Utah reports that crested wheat grass developed into the boot stage in his study area during 1980 by the 3rd week in May; and seeds were developing well by the first of June. The plants grew quickly this year during the summer.

Production

The best combination of temperature and precipitation for predicting unfertilized mature yield was July-May precipitation plus mean March, April and May temperatures at the Oregon site of this study. (Sneva 1977) The February temperature combined with March precipitation accounted for 83% of the variability in spring yield at this study site. By the time the mature stage was reached in July, additional moisture did little to increase

the yield.

PROCEDURES AND TECHNIQUES

As was indicated previously, the work on modeling of tomatoes and the competing weed species indicated strongly that the growth curve defined by a combination of equations 1 and 2 increased the predictive accuracy considerably over the results achieved with equation 1 only. Use of the two equations requires the determination or estimation of three cardinal temperatures for each species rather than only two.

Cardinal Temperature Selection

The review of the literature previously reported on failed to supply specific cardinal temperature information for all of the species in particular values of TC. There were even contradictions on the values for the other two temperatures but it appears that a good starting point for the four species under consideration will be the following: TB = 4°C (39°F), TU = 25°C (77°F) and TC = 36°C (96.8°F). The 36°C value was selected since in all of the modeling of this type to date the rate of decrease of plant development as temperatures increase above the optimum temperature has always been much more rapid than the rate of increase in development as temperatures increase below the optimum temperature.

After our literature review and finding very little information on the cardinal temperatures for the different plant species, we propose to use the following general categories until more specific values can be measured:

TABLE 2

Cardinal Temperatures for Three Plant Categories

Plant Type	TB	TU	TC
Cool Temperature Plants	0°C (32°F)	20°C (70°F)	32°C (90°F)
Intermediate Temp. Plants	4°C (39°F)	25°C (77°F)	36°C (97°F)
Warm Temperature Plants	10°C (50°F)	30°C (86°F)	42°C (108°F)

In the reviewed literature, several of the plant species had reports of different cardinal temperature classifications, but the strongest evidence points to the four species under study falling in the intermediate category.

Soil Moisture Content

The values of the moisture content of the soil at the wilting point (WP) and field capacity (FC) were extracted from the SCS soil survey reports. The values for the soil at Price were fairly site specific, but data of equivalent accuracy could not be obtained for the Vernal site since the phenology data were taken over a wide range of elevations and locations in the Vernal area. On the basis of the general soil classifications in the area, it appeared that the same values could be used for both sites in the preliminary modeling efforts. Values of WP = 55 mm (2.17 inches) and FC = 127 mm (5.0 inches) were selected. Since the winter of 1977-78 and 1978-79 at both Price and Vernal were relatively dry it was assumed that the moisture content of the soil at the beginning of the growing season was only 50% of field capacity at both sites.

As constants for calculating the influence of moisture on the accumulation of GDH, it was assumed that the date the snow cover disappeared was March 1, (day number 182 on the modified Julian calendar which begins September 1). It was further assumed that the length of the growing season at Price was 140 days and at Vernal 120 days when calculating the moisture usage by the plants.

There was not sufficient information available to test our current method of calculating evapotranspiration and the influence of soil moisture content on the specific species. Surface texture characteristics have a significant affect on available soil moisture in low precipitation climate

regimes (less than 12 inches annually). The General soil classification does not reflect these surface texture influences. Some actual values of the amount of moisture in the soil are required to refine the soil moisture calculations. These improvements may modify the numerical value of the GDH constants for the various phenological stages, the height and the biomass calculations developed in the current research; but once the more accurate values are determined, the results will have a much broader spatial range of application.

Estimating the Beginning of Growth

No information on the time growth began was available at any of the observational sites for any plant species. It was therefore necessary to estimate the beginning dates. Winter temperatures in most areas of Utah are too cold for any form of plant growth. The assumption was therefore made that growth began on the date in the spring when the first accumulation of growing degree hours for the season was accumulated and followed by at least four additional days with temperatures warm enough to continue the accumulation. The dates of beginning of growth thus determined are shown in the phenology tables in the appendix.

Since the literature review indicated that, in general, the species selected for study all would fall in the intermediate temperature category of TB = 4°C, TU = 25°C and TC = 36°C, this set of cardinal temperatures was used in the modeling work being reported.

Calculating GDH data and Relating to Height, Phenology and Production

The GDH calculations were made using equations (1) and (2) and the constants discussed previously. A sample of the output from the computer has been included in the appendix in Table 23.

To develop the GDH requirements for the desired phenological dates,

the accumulation from the calculated beginning date of growth to each desired stage of development was determined for each available year and site. The accumulations for the various species have been included in the appendix tables as indicated. The requirements for the various heights and various determinations of biomass were determined in a similar manner and have also been included in the tables.

CONFIDENCE LEVELS ACHIEVED FOR OUTPUTS BY SPECIES

The data that was available from the BLM areas for the selected species was not sufficient to run any valid statistical tests to evaluate either the correlation or levels of confidence. Graphs which show the scatter of the data points about an estimated average curve have been included for each of the key species where sufficient information was available.

Discussion of Results by Species

Stipa comata--needle and thread grass

As indicated in table 3A in the appendix, information for only two years was available for this species: Vernal 1979 and Vernal 1980. To further complicate the situation, the data for 1979 was measured at an elevation of 8600 feet above sea level while the 1980 information was observed at only 6000 feet above sea level. The weather station at Vernal is located at an elevation of 5280 feet above sea level.

Orizopsis hymenoides--Indian Rice Grass

There was little more information available on Orizopsis hymenoides than for Stipa comata. Although the information for the two years was collected on opposite sides of the basin, they were observed at about the same elevation. Only three height measurements were taken and the observer

indicates that she is quite doubtful of the validity of them.

The estimated GDH accumulations for the various phenological stages and the limited height and biomass information have been tabulated in Table 5, 6 and 7. Again, these values are very preliminary due to the quality and limited amount of basic data. A very preliminary dryweight Biomass versus accumulated growing degree hours curve has been plotted in Figure 3. There is considerable scatter to the few points but the trend is readily demonstrated.

Agropyron cristatum--crested wheat grass

More data was available for crested wheat grass than for any of the other species, but again there is a problem with the 1980 information at Vernal being taken at an elevation of 6600 feet above sea level while the observational station was located at only 5280 feet. The basic information has been tabulated in Table $3C_1$ and $3C_2$ in the appendix. A comparison of the accumulations of growing degree hours for the various phenological stages indicates that the coefficient of variation is reasonably small, although with the small quantity of data these should be interpreted with caution.

The coefficient of variation (CV) for the boot stage is 7.4% but with only three observations. The peak flower CV = 2.0% with four observations, the seed ripe stage CV = 18.0% with 4 observations, and for the seed disseminate stage CV = 7.2% again with 4 observations.

The beginning of vegetative growth shows a large difference between the accumulations at Price and the accumulations at Vernal. This is due to a difference in the interpretation of the definition of that stage of development by the different observers.

The fit of both the height and biomass data (Figures 4 and 5) is much

better than any of the other species, but there is still considerable scatter. However, when one considers the problems of obtaining reliable data of this type, the fit is surprisingly good.

The analysis of Agropyron cristatum indicates the potential for application of this form of modeling to the determination of range development and production quite well. If we eliminate from the data those points which show a decrease in production after a larger GDH accumulation, the correlation coefficient between biomass and accumulated GDH is 88% with a standard error of 2209 GDH. If all of the available data points are considered, the correlation coefficient is 63% with a standard error of 8203 GDH. Once again it should be recognized that such statistics are not statistically conclusive when one considers the limited amount upon which they are based.

Hilaria jamesii--galleta grass

Data on galleta grass was available for only three years: 1978 at Price, 1979 at Vernal and 1980 at Vernal. Again, we were unable to utilize 1980 data since it was observed at an elevation of only 4800 feet above sea level. Due to the nature of the basin, it was again assumed that the Vernal 1979 data would be fairly compatible even though the observations were taken at 6,000 feet above sea level. In determining the GDH requirements for the various phenological stages, we again encountered some problems in the vegetative growth stage (see Table $3D_1$ in the appendix). There was also a difference in the accumulated GDH for the boot stage; but the peak flowering, seed ripe and seed disseminate accumulations are quite close for the Price 1978 and Vernal 1979 observations. The averages required for the various stages as used in the predictive equations have been tabulated in Tables 5, 6 and 7.

The graphs of Dry weight versus GDH and Height versus GDH are shown in Figures 6 and 7. Again, there was not sufficient data for valid statistical tests; but the degree of scatter indicates a fairly reliable relationship. The Biomass data for 1980 were also plotted, but it appears that the information as tabulated may have been off by a factor of 10. The biomass data at Price was the sum of the total weight sampled and not that of individual plants; but when we assumed a sample of 10 plants, the values of the production trends were similar. Analyzing the five samples during 1979 showed a correlation coefficient of 97.7% and a standard error of 566 for this year which was the only one with what we considered as reliable data. These are poor statistics but does give a rough idea of the relationship and the potential for predicting biomass of this species.

Atriplex canescens--four wing salt bush

Only one year of information was available for this species: Vernal 1979. There was no indication of the elevation at which these observations were taken, but the information was evaluated assuming that the data may have been representative of the weather station elevation. The basic data tabulation can be found in the appendix Table 3E. The limited Biomass and height information has been plotted in Figures 8 and 9. The information does show a fair fit to the general production curve found in the other species. This is of course only a very rough approximation of the actual modeling curves.

Artemesia Tridentata--Sage brush

Since only limited amounts of data were available for the selected species, a plot was also made of sage brush since the elevation of the

observational sites for this species were fairly representative of the weather station at Vernal. Here again, we found that the information was not very satisfactory. I suspect that the leader length data at Vernal during 1979 may have been expressed in millimeters instead of centimeters, but I can't be certain. The biomass information was not compatible with the various sites either; hence, the plots were not included in the summary. The phenology data appears to be a little better and the average GDH accumulations can be found in Table 9.

COMPARISON OF OBSERVED AND CALCULATED PRODUCTION WITH NORMAL VALUES

One question that is a very important consideration in range management is "How does the current year's production compare with normal production in any particular area. To evaluate the use of the model in answering this type of question, normal temperature and precipitation values for both Vernal and Price were entered into the model to predict the normal production. Two runs were made. The first assumed that the soil moisture at the beginning of the growing season was 50% of field capacity, the same values assumed in developing the models. The second assumed that the soil moisture was 100% of field capacity. The 50% run resulted in predicted production not too different from the values obtained by inputing the temperature and precipitation for the specific years for which data was available. (Figure 10)

When the observed production values were averaged over the growing season and compared with predicted normal values based on 100% of field capacity, the 1979 average production at Price was 83% of normal. The 1980 production at Vernal was 88% of the calculated normal production at that site. The 1979 production at Vernal was 107% of the calculated normal.

In determining the actual production figures, those observed values which were followed by lower production measurements were assumed in error and discarded in making the average calculations for the season. The production figures at Vernal in 1979, for example, showed much larger variations than either of the other season's measurements. The measured values have been tabulated in Table 17.

A second test compared the production values as predicted by the models for each year with the predicted normal values in each study site. The values for Agropyron cristatum and Hilaria jamesii have been plotted in Figures 11 and 12. It will be noted that the average production as calculated for each year is less than the calculated normal production. These tests indicate that with more accurate dry weight biomass information such predicted comparisons will be very practical.

SUGGESTED PROCEDURES FOR EXPANDING PHENOCLIMATOGRAPHY MODELS TO ALL MAJOR OR IMPORTANT RANGE LAND SPECIES

From an analysis of the species studied in the current project combined with other modeling efforts during the past few years, it is now possible to pinpoint the more important soil and atmospheric factors which relate to phenological, growth and production of specific range species. To expand the modeling program and increase its accuracy, we need to collect the following types of information for the desired sites and species:

A. Soils Data

1. Wilting point (determined from a soil analysis)
2. Field Capacity (also determined from a soils analysis)
3. Soil moisture content for at least three depth intervals i.e. 0 to 30, 30 to 60, 60 to 90 cms. (0 to 1, 1 to 2, and

2 to 3 feet). This information needs to be collected at the beginning of the growing season and at about 3 week intervals during the season.

4. Daily maximum and minimum soil temperatures at the 10 cm. (4 inch) depth throughout the year.

B. Atmospheric data

1. Daily maximum and minimum air temperatures as measured in a standard instrument shelter during the entire year.

2. Daily precipitation measurements during the entire year.

3. Date the snow disappears if possible each year.

C. Plant information

1. Phenological stages for desired species including:

a. First observed signs of growth.

b. Green Up.

c. Observable stages of vegetative growth such as the number of leaves and date they occur. These data will vary with the species under study.

d. Fruiting stages such as: the beginning of development of the inflorescence, boot, first bloom, peak bloom, seed ripe, seed disseminate, etc.

e. Timing and amount of fall regrowth and determination of how much carries over into the following spring.

2. Height information or leader length at regular intervals and record of date on which each observation was taken.

3. Dry weight biomass. Average per culm or individual leader. Should be collected at regular intervals. Weights must be carefully checked and the date of each observation recorded.

4. Estimates of average percent of plant cover on each observational date. These data are required to estimate changes in effective evapotranspiration on the range.

D. Non-field determinations from the literature or laboratory and/or growth chamber studies as needed.

1. Cardinal temperatures for each species.

2. Unique growth and development characteristics.

3. Daylength sensitivity

4. Influence of critical stress factors such as atmospheric stress, soil moisture stress, disease stress, insect stress, grazing stress, etc. on plant growth and development.

With the above information as input data to the preliminary computer program which has already been developed, the GDH-phenology, GDH-Height and GDH-dryweight biomass models can be developed for each desired species. Once the model constants have been determined and tested over a diverse range of climate and soil conditions, the models can be used to predict the desired variables wherever the necessary soil and climate information is available.

Once the models have been perfected, it will be possible to utilize climate information from long term weather stations to study trends in development and relate such trends to cultural practices on the range and evaluate the influence of such stress factors as drought, cold temperatures, excessive moisture, overgrazing, etc.

FEASIBILITY AND USE OF PHENOCLIMATOGRAPHY MODELS IN RANGE MANAGEMENT

The manager of western rangelands is continually faced with a multitude of conflicting requirements. (Pressure groups, many of whom are lacking in a knowledge of the basic facts, are continually pressing for utilization of the ranges in a manner which they feel will best suit their own personal desires. Many such pressures are quite self-centered, selfish, and personally motivated.)

Most of the current decisions which must be made involve elements that create an impact on the air, soil and water aspects of the environment and may have very important influences on the welfare of plants and animals on the range. (Such factors are generally interactive and present

knowlege on how to predict such interactions is far from adequate.)

Perhaps the most important use of the models is the prediction of phenological development and production for use in grazing management. Grazing treatments are usually keyed on plant development and/or an allowable utilization of current year production of key species. In the past, timing of grazing treatments has been designed around dates representing plant development and production estimates for a "normal" year. To achieve maximum plant response or benefit to the user, grazing management should be flexible enough to allow treatments to be initiated as closely as possible to the actual occurrence of the phenological stage or utilization level desired.

(Modeling cannot, of course, replace actual field observations by the trained range manager; but it can provide a valuable tool for increasing the scope and efficiency of limited field observations for making broader management decisions.)

Another important use of the models is in prediction of range readiness and production. When sufficient climate/weather information is available to establish long term averages or normal temperature and moisture data, the current year's information is used as far as available and the assumption is made that beyond this period, normal temperatures and moisture conditions will occur. Using this assumption, it is possible to predict each year at any desired time the stage of development of the desired species and the estimated production. (It is also possible to vary the estimates in terms of departures from normal, either above or below, during the period when normals are used in the predictive model. As new current weather information becomes available, the predictions can be updated as frequently as desired to obtain more recent predictive

results for guiding the range manager in his decision making.)

A third application of the models is to use them as a form of environmental control of weather factors in field and range experiments. In the past the value of many field experiments was limited because the variable nature of weather and its influence at the time the experiments were performed was not usually evaluated. Even in their current juvenile state of development, these models will enable researchers to eliminate to a certain extent the influence of weather conditions on field experiments by enabling researchers to compare conditions at the time of their own research with the development which would occur under normal conditions or in any other particular year or season. Researchers can thus define more closely the impact of other influences which might be modifying the growth and development of the plants since the influence of variable weather conditions can be partially eliminated.

The models also permit the range manager to evaluate the influence on a longer time scale of various cultural and management decisions. For example, the production on the range as evaluated by the model is plotted in comparison with the observed information over a period of years. It is then possible to detect trends in departures from the potential production or development which can in many cases be related to certain management decisions.

It is also possible by use of the models to calculate production over the full period of weather records, to compare these with available observed production data and to analyze trends in production over a longer period of time than actual production data may be able to supply. Such a study will enable the range manager to better understand the potential influence on production of future periods of drought, excessive

moisture, abnormally cold or warm temperatures or current grazing practices on total range production. The range manager can further be better prepared to develop contingency plans for reducing the economic impact of such extreme weather occurrences on the users of the range. The immediate effects of the drought or other abnormal weather occurrences can also be quantified and analyzed as they relate to adjustments in livestock numbers, periods of use or supplemental feed requirements.

Since the models can predict the influence of varying temperatures and moisture regimes on range production, even if not perfectly, it is also possible to utilize them in predicting the economic values of such practices as addition of fertilizer, reduction of competing of nondesirable plant species and the impact of increased insect populations on production.

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APPENDIX

TABLE 3

DATA AVAILABLE FOR MODEL
DEVELOPMENT AND TESTING FROM PRICE, UTAH

Species	Years	Phenology	Height or Leader Lengths	Biomass Total
*AGDE2	1978	X	X	X
*AGDE2	1979	X	X	
*HIJA	1978	X	X	X
ARTR2	1978	X	X	X
ARTR2	1979	X	X	
OPPO	1978	X	X	
OPPO	1979	X	X	
SAKA	1978	X	X	
SAKA	1979	X	X	

*These were the only data for the desired key species to be modeled.

TABLE 4

DATA AVAILABLE FOR MODEL
DEVELOPMENT AND TESTING FROM VERNAL, UTAH

Species	Site Elevations*	Years	Phenology	Height or Leader Lengths	Biomass Per Culm Or Leader
HIJA	5800	1979	X	X	X
HIJA	4800	1980	X		X
ORHY	5800	1979	X	X	X
ORHY	6000	1980	X		X
SAKAT	5100	1979	X		X
AGCR	7000	1979	X	X	X
AGCR	6600	1980	X		X
STCO4	8600	1979	X		X
STCO4	6000	1980	X		X
ATCA	5800?	1979	X	X	

*The weather station at Vernal is located at an elevation of 5280 feet above sea level, but reading from the topographic maps the locations given, the data was collected at elevations ranging from 4800 feet above sea level to 8600 feet; and in some cases, on different sides of the Uinta Basin.

TABLE 5

Grasses: GDH accumulation for related phenological stages

Phenology stages	ORHY	AGCR	HIJA
1. Begin Growth	0	0	0
2. Two Leaves		1100	2200
3. Three Leaves		1900	3700
4. Four Leaves		3100	5200
5. Five Leaves		5000	6900
6. Boot	6425	6309	7006
7. First Flower			
8. Peak Flower	9188	9571	9927
9. Peak Seed Ripe	11622	12802	11716
10. Seed Dissemination	12675	16933	14402

TABLE 6

Grasses: GDH accumulation for related heights

Heights (cm)	5	10	15	20	25	30	35	40
HIJA	2600	5900	9300					
AGCR	1100	2500	3700	5000	6700	9200		
ORHY	1500	3600	7000					

TABLE 7

Grasses: GDH accumulation for selected plants for dry weight biomass

Biomass (gms)	5	10	15	20	25	30	35	40	45	50
AGCR	1300	2700	4300	6200	8500	11400	14500			
HIJA*	4700	8300	11000	13000						
ORHY	2000	3500	4900	6000	6900	7600	8200	8700	9300	9800

* Biomass X 10^{-1} grams

The growth of the seed stalk or infloresence apparently does not begin until the grass plant reaches a certain stage of development. In terms of growing degree hours, the required accumulation before the plant is sensitive to daylength as a trigger is on the order of 2000 to 2500 GDH. This accumulation seems to correspond to a stage of development ranging between 3 leaf and 5 leaf stages depending upon the grass species.

Utilizing the above assumption, the following table shows the relationship between the height of the infloresence and the accumulation of GDH. Development of the infloresence is assumed as 0 cm's at 2500 GDH.

TABLE 8

Grasses: GDH accumulation compared to height of infloresence

Heights	5	10	15	20	25	30	35	40	45	50	55
AGCR	2800	3100	3500	4100	5000	5900	6900	8100	9500	11200	13200
HIJA	3300	4300	5400	6400	7500	8700	10100	11700			
ORHY	3100	3800	4600	5800	7000	8300	10000	12200			

TABLE 9

Shrubs: GDH accumulation for selected phenological stages

Phenological stages	ATCA
1. Begin growth	0
2. Green Up	
3. Vegetative Stage	7343
4. Floral Bud Development	11621
5. First Flower	
6. Peak Flower	21053
7. Seed Ripe	23988
8. Seed Dissemination	26080

TABLE 10

Shrubs: GDH accumulation for selected plant leader length

Lengths (Cms)	10	20	30	40	50	60	70
ATCA *	800	1600	2500	3400	4700	6100	8100

* Based on very limited information. The lengths reported seem to be out of line with more normal plant growth for the species.

TABLE 11

Shrubs: GDH accumulation for selected plant dry weight biomass

Biomass (gms)	5	10	15	20	25	30
ATCA*	2000	3900	5900	8000	10800	14900

*These weights are quite questionable but do follow a good curve.

TABLE 12

ARTEMESIA TRIDENTATA

Phenology, Height and Biomass

	Begin Growth	Green Up	Vegetative Growth	Floral Buds Develop	Start Flower	Peak Flower	Peak Seed Ripe	Seed Disseminate	Dormancy	Elevation
Vernal '79 Dates	3/13		5/22	6/5		9/25	10/18			5,800
ACC GDH	0		5,295	7,500		23,988	26,560			
Dry Weight Biomass/leader			14 gms	24 gms		18 gms	29 gms			
Avg leader length			82 cms	67 cms		61 cms	79 cms			
Vernal '80 Dates	2/14	4/29	5/20		7/21					6,000
ACC GDH	0	3,228	5,457		14,350					
Dry Weight Biomass/Leader		.29 gms	.09 gms		.30 gms					
Avg leader length		--	--		--					
Price '78 Dates	2/26	.4/29	5/22		7/11	10/9	10/25	11/7		
ACC GDH	0	3,000	5,352		13,406	26,435	28,839	29,610		
Price '79 Dates	2/28	4/20			7/1	9/25				
ACC GDH		2,090			11,605	25,706				
				Dry Weight Biomass/Leader						
Price '78 Dates	2/26		5/22	6/19	7/5	7/18	7/25	8/8	8/22	
ACC GDH	0		5,352	9,746	12,405	14,490	15,616	17,662	19,928	
Biomass Dry Weight			0.9 gms	1.4 gms	1.3 gms	0.9 gms	0.9 gms	1.5 gms	1.4 gms	

TABLE 13

ORYZOPSIS HYMENOIDES (Indian Rice Grass)

Phenology and Dry Weight Biomass

	Begin Growth	Green Up	Vegetative Growth	Boot	First Flower	Peak Flower	Peak Seed Ripe	Seed Disseminate	Dormancy	Elevation
Vernal '79 Dates	3/13		5/22	5/30		6/25	7/9			5,800
ACC GDH			5,295	6,612		10,108	12,211			
Wt of Culm			18 gms	35 gms		59 gms	80 gms			
Height			12 cm			18 cm	40 cm			
Vernal '80 Dates	2/14		5/13	5/27		6/11	6/30	7/10		6,000
ACC GDH			4,765	6,237		8,267	11,034	12,675		
Wt of Culm			7 gms	21 gms		36 gms	30 gms			
Height			--	--		--	--			

TABLE 14

STIPA COMATA (Needle and Thread Grass)

Phenology and Dry Weight Biomass

	Begin Growth	Green Up	Vegetative Growth	Boot	First Flower	Peak Flower	Peak Ripe	Seed Disseminate	Dormancy	Elevation
Vernal '79 Dates	4/13		6/6	6/14		7/6	7/12	7/27		8,600
ACC GDH	0		7,500	8,491		11,790	12,644	14,956		
Wt of Culm			7 gms	23 gms		36 gms	27 gms	30 gms		
Height			24 cm			18 cm	34 cm			
Vernal '80 Dates	2/14		4/29	5/27		6/24	6/30	7/10		6,000
ACC GDH	0		3,228	6,237		10,144	11,034	12,675		
Dry Wt of Culm			14 gms	18 gms		40 gms	40 gms	38 gms		
Height										

TABLE 15

HILARIA JAMESII (Galleta Grass)

Phenology and Dry Wt Biomass

	Begin Growth	Green Up	Vegetative Growth	Boot	Start Flower	Peak Flower	Peak Seed Ripe	Seed Disseminate	Dormancy	Elevation
Price '78 Dates	2/26		4/2	5/18	6/2	6/19	6/28	7/18	9/25	6,000
ACC GDH	0		1,238	4,906	6,971	9,746	11,220	14,490	24,936	
Dry Wt Biomass	Total			5/25 13.5 gms		16.2 gms	16.4 gms	16.5 gms		
Vernal '79 Dates	3/13		5/30	6/18		6/25	7/9	7/23		5,800
ACC GDH	0		6,612	9,106		10,108	12,211	14,314		
Dry Wt Biomass/Culm			0.7 gms	1.2 gms		1.2 gms	2.0 gms	2.2 gms		
Vernal '80 Dates	2/14		5/7	5/14		5/22	6/12	6/25		4,800
ACC GDH	0		4,298	4,850		6,346	9,253	10,277		
Dry Wt Biomass/Culm			.06 gms	.05 gms		.20 gms	.16 gms			

TABLE 16

HILARIA JAMESII

Height Data

Price 1978 Dates	4/4	4/25	5/8	5/18	6/2	6/19	6/28	7/18	7/25	8/8	8/22	9/12	9/25	10/25
Leaf Stage	1-2 Leaves	2-3 Leaves	3 leaf	3 leaf	5 leaf.	5 leaf	Flowers Beginning to dry	Seeds Mostly Gone 6 leaf		Leaves Drying Out	30-35% Dry	No Growth Still Green Near Wash	Varying Amounts of Regrowth Near Wash	No change
Average Ht	1-2 cms	4 cms	5-7 cms	7-10 cms	inflores-cence Ht 20 cms	Leaf Ht 15-17 cms inflores-cence 30 cms		inflores-cence stalks drying out	15-17 cms Ht.					
ACC GDH 5800	1,334	3,000	3,739	4,906	6,971	9,746	11,220	14,490	15,619	17,662	19,928	23,480	24,936	28,839
Vernal 1979 Dates					5/30		6/25	7/9	7/23					
Leaf Stage					Probably Ht of inflores-cence		Probably Ht of inflores-cence	Probably Ht of inflores-cence	Probably Ht of inflores-cence					
Average Ht					18.3 cms		24.4 cms	45.7 cms	15.2 cms					
ACC GDH					6,612		10,108	12,211	14,314					

TABLE 17

AGROPYRON CRISTATUM (Crested Wheat Grass)

Phenology and Dry Weight Biomass

	Begin Growth	Green Up	Vegetative Growth	Boot Stage	Start Flower	Peak Flower	Peak Seed Ripe	Seed Disseminate	Dormancy	Elevation
Price '78 Dates	2/26		3/25	5/25	6/2	6/19	6/28	8/8	9/25	6,000
ACC GDH	0		539	5,781	6,971	9,746	11,220	17,662	24,936	
Dry Weight Biomass				17.8 gms		20.7 gms	26.8 gms			
Price '79 Dates	3/3	4/1	4/5		6/5	6/19	6/26	7/23	8/22	6,000
ACC GDH	0	368	496		7,661	9,724	10,812	15,117	19,901	
Dry Weight Biomass			--		--	--	--	--	--	
Vernal '79 Dates	3/13	4/24	5/23	5/31		6/20	7/17	8/13		5,800
ACC GDH	0	2,532	5,454	6,682		9,391	13,347	17,434		
ACC Biomass Dry Weight/Culm		18 gms	35 gms	22 gms		35 gms	35 gms	41 gms		
Vernal '80 Dates	2/15	4/29	5/14	5/29		6/19	7/31	8/12		6,600
ACC GDH	0	3,229	4,850	6,463		9,424	15,829	17,520		
ACC Biomass Dry Weight/Culm		18 gms	17 gms	17 gms		22 gms	34 gms	20 gms		

TABLE 18
AGROPYRON CRISTATUM
Height Data

Price '78 Dates	Begin 2/26	3/21	4/4	4/25	5/8	5/18	6/2	6/19	6/28	7/18	7/25	8/8	8/22	9/12	9/25
Leaf Stages		2 leaves	3 leaf	4 leaf	4-5 leaf	5 leaf	in flower	full flower	seeds develop	peak seed ripe	peak seed ripe	seeds dissem-inate	seeds dis-seminate leaves dry	seeds dis-seminate culm green	plants dry
Average Ht.		5 cms	5-6 cms	12 cms	15-20 cms	25-30 cms	inflores-cence 40 cms	leaf 30cms inflores-cence 40-45 cms	inflores-cence 45-50 cms	inflores-cence 48-54 cms	inflores-cence 60 cms				
ACC GDH	0	228	1334	2908	3739	4906	6971	9746	11,220	14,490	15,619	17,661	19,928	23,480	24,936
Price '79 Dates	3/3	4/1		4/26		5/21		6/19	7/3	7/19	7/31		8/22	9/10	
Leaf Stages				3-4 leaf		3-4 leaf		full flower	seeds develop	seeds dissem-inate	seeds dissem-inate				
Average Ht				10-15 cms		15-25 cms		5-61 cms							
ACC GDH	0	369		2909		5498		9725	11,958	14,436	16,334		19,901	23,126	
Vernal '79 Dates				4/24		5/23	5/31	6/20		7/17		8/13			
Leaf Stages							Boot Stage	Peak Flower		Peak Seed Ripe		Seed Dissem-inate			
Average Ht				12 cms				46 cms		70 cms		55 cms			
ACC GDH				2532		5454	6682	9391		13347		17434			

TABLE 19

ATRIPLEX CANESCENS (Four Wing Salt Bush)

Phenology

	Begin Growth	Green Up	Vegetative Growth	Floral Buds Develop	Peak Flower	Seed Ripe	Seed Disseminate
Vernal '79 Dates	2/13		6/5	7/15	9/5	9/25	10/12
ACC GDH	0		7,343	11,621	21,053	23,988	26,080
Dry Wt/leader			17 gms	28 gms	28 gms	33 gms	35 gms
Length of leader			67 cms	79 cms		46 cms	

TABLE 20

Species Name: _____ Annual, Perenial, Grass, Forb, Shrub, Tree (Underline)

SEED

Description:

GERMINATION REQUIREMENTS	Lower Lethal	Base	Optimum	Critical	Upper Lethal
Scarification					
Vernalization (chilling)					
Soil Temperature					
Soil Moisture					
Light Intensity					
Light Duration (day length)					
Light Quality					
Other					

Notes:

TABLE 21

Species Name: _____

VEGETATIVE STAGES

Name and description of recognizable stages of development

Climate Factors	Lower Lethal	Base	Optimum	Critical	Upper Lethal
Temperature					
Humidity					
Soil Moisture					
Daylength					
Light Intensity					
Light Quality					
Nutrient Requirements					
Other					
Stress Factors					
Disease					
Insects					
Other					

Notes on back

TABLE 22

Species Name: _____

FRUITING STAGES

Names and descriptions of recognizable stages of development:

Climate Requirements and triggers	Lower Lethal	Base	Optimum	Critical	Upper Lethal
Temperature					
Mositure					
Humidity					
Daylength					
Light Intensity					
Light Quality					
Other					

Notes:

TABLE 23

SAMPLE OF COMPUTER OUTPUT

SPECIES: STCO

DAY # OF PHENOL. STAGE DEVEL.

Stage #	1	2	3	4	5	6	7	8
Predicted Day	0	0	260	282	0	308	314	325

DAY # OF HEIGHT LEVELS (CM)

Height	5	10	15	20	25	30	35	40
Predicted Day	0	0	0	0	0	0	0	0

DAY # OF BIOMASS DEVEL. (GMS)

Dry weight Biomass	5	10	15	20	25	30	35	40
Predicted Day	247	265	275	284	292	298	303	308

TABLE 24

Comparison of Predicted Actual and Normal Dates For

AGROPYRON CRISTATUM

Phenology

	Begin Growth	Leaf	Leaf	Leaf	Leaf	Boot	First Flower	Peak Flower	Peak Seed Ripe	Seed Disperse
Vernal 1977-78		216	227	249	265	276		302	325	351
Vernal 1978-79		234	244	265	271	282		304	326	353
Vernal Normals										
AW = 50%		232	244	257	272	282		304	325	351
AW = 100%		221	231	244	262	273		295	316	343
Price 1978-79		233	242	258	269	279		301	321	347
Price Normals										
AW = 100%		215	226	240	257	267		288	307	332

Height of Culm

	5 cm	10 cm	15 cm	20 cm	25 cm	30 cm
Vernal 1977-78	216	237	255	265	279	300
Vernal 1978-79	234	254	263	271	285	302
Vernal Normal						
AW = 50%	232	251	262	272	285	301
AW = 100%	221	237	250	262	276	293
Price 1977=78	233	252	261	269	282	298
Price Normal						
AW = 100%	215	233	246	257	269	285

TABLE 25

Comparison of Predicted Actual and Normal Dates For

HILARIA JAMESII

Phenology

	Begin Growth	Leaf	Leaf	Leaf	Leaf	Boot	First Flower	Peak Flower	Peak Seed Ripe	Seed Disperse
Vernal 1977-78		233	255	267	280	281		304	316	335
Vernal 1978-79	194	247	263	272	286	287		307	319	336
Vernal Normals AW = 100%		234	250	264	277	278		298	309	327
Price 1978-79		245	261	270	283	284		303	314	331
Price Normals AW = 100%		230	246	258	271	272		290	300	316

Height of culm

	0.5 cm	1.0 cm	1.5 cm	2.0 cm	2.5 cm	3.0 cm
Vernal 1977-78	239	274	300			
Vernal 1978-79	255	278	303			
Vernal Normal AW = 100%	239	270	294			
Price 1978-79	254	276	299			
Price Normal AW = 100%	234	264	286			

Figure 3

ORIZOPSIS HYMENOIDES

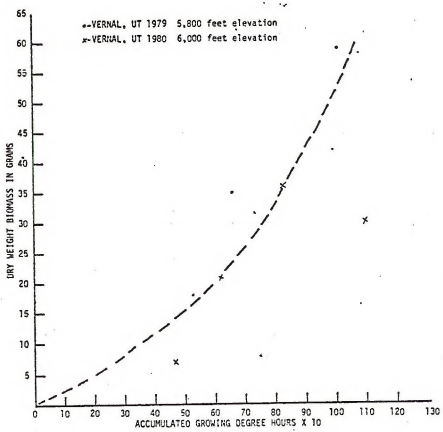

•-VERNAL, UT 1979 5,800 feet elevation
x-VERNAL, UT 1980 6,000 feet elevation
DRY WEIGHT BIOMASS IN GRAMS
ACCUMULATED GROWING DEGREE HOURS X 10

Figure 4

AGROPYRON CRISTATUM (Crested Wheat Grass) AGCR

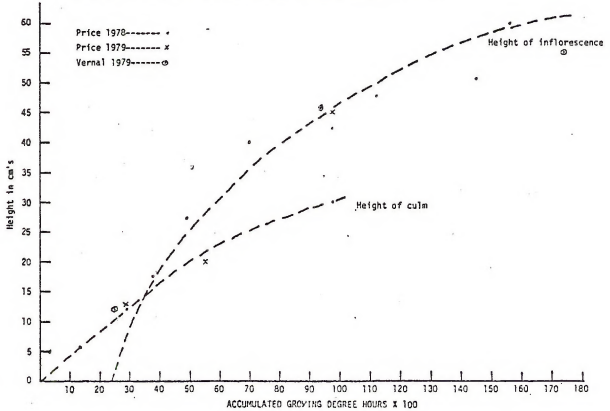


Figure 5

AGROPYRON CRISTATUM (Crested Wheat Grass) AGCR

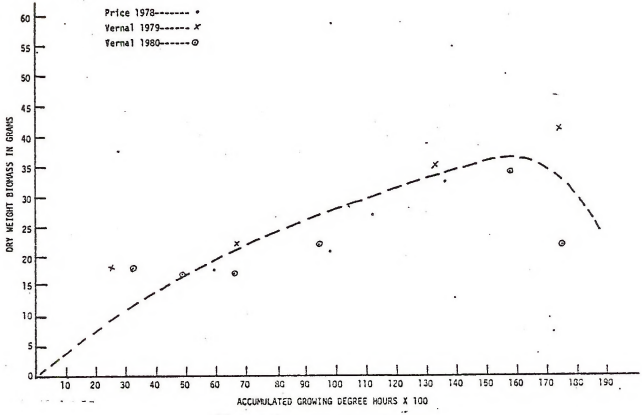


Figure 6

HILARIA JAMESII (Galleta Grass) HIJA

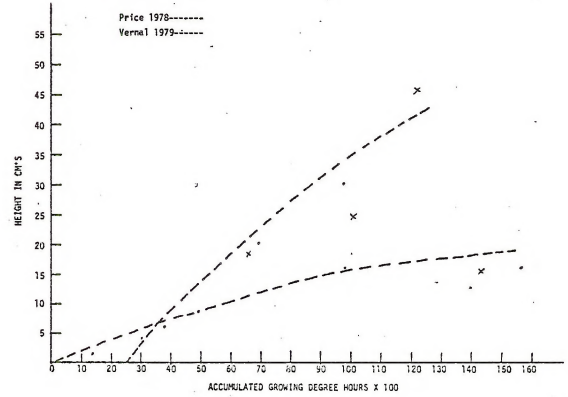


Figure 7

HILARIA JAMESII (Galleta Grass) HIJA

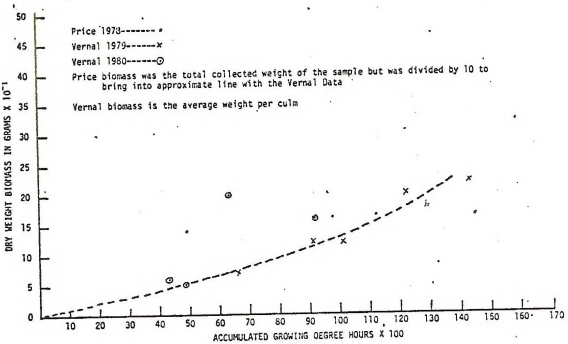

Price 1978-------*
Vernal 1979------x
Vernal 1980------⊙
Price biomass was the total collected weight of the sample but was divided by 10 to bring into approximate line with the Vernal Data
Vernal biomass is the average weight per culm
DRY WEIGHT BIOMASS IN GRAMS X 10⁻¹
ACCUMULATED GROWING DEGREE HOURS X 100

Figure 8

ATRIPLEX CANESCENS (Four Wing Salt Bush) ATCA

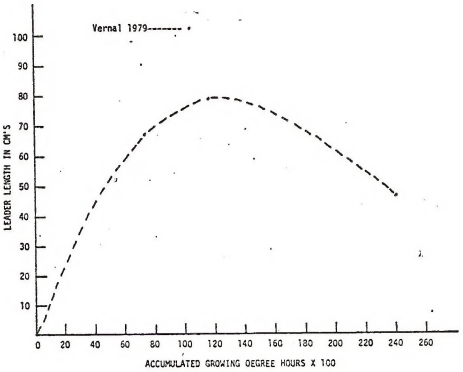


Figure 9

ATRIPLEX CANESCENS (Four Wing Salt Bush) ATCA

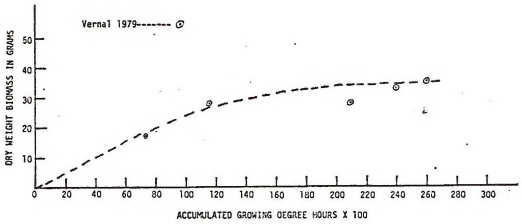


Figure 10

AGROPYRON CRISTATUM (Crested Wheat Grass)

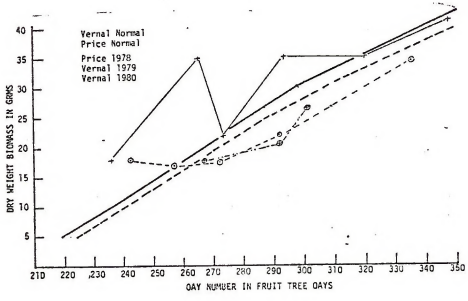


Figure 11

AGROPYRON CRISTATUM

DRY WEIGHT BIOMASS vs PREDICTED DATES

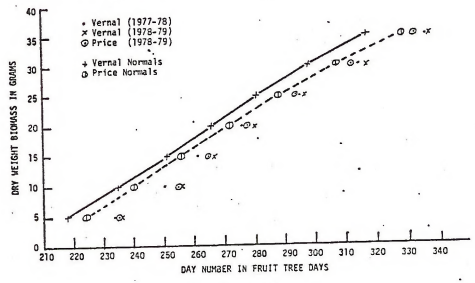
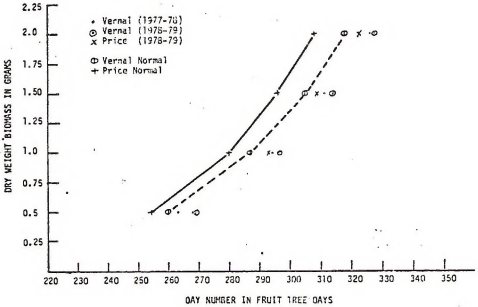


Figure 12

HILARIE JAMESII

DRY WEIGHT BIOMASS vs PREDICTED DATES



```
      C----
      C---- THIS IS A PROGRAM OF A RANGE MODEL USED TO PREDICT PHENOLOGY,
      C---- GROWTH AND PEAK ABOVE GROUND SEASONAL PRODUCTION
      C----
      C----
      FILE  5(KIND=REMOTE)
      FILE  6(KIND=REMOTE)
      FILE  7(KIND=PRINTER)
      FILE  8(KIND=PACK,FILETYPE=8,TITLE='VRN078')
      FILE  13(KIND=PACK,FILETYPE=8,TITLE='VRNCAL')
            DIMENSION LAN(2),NCON(2),NAN(2),LCON(2),IXNT(475,2),IXNP(475)
            COMMON /BLK1/ XNP(475),XNT(475,2),ET(475),EA(475)
            COMMON /BLK2/ NG(475),SP(2,10),NDGDH(475)
            COMMON /BLK3/ AW(475),TRAT(4)
        20  WRITE(6,10)
        10  FORMAT(' ',' PLEASE ENTER THE STATION#'/)
            READ(5,700) IST
       700  FORMAT(I6)
            IF(IST.EQ.0)GO TO 9999
            DO 29 M=1,475
            ET(M)=0.0
            EA(M)=0.0
        29  CONTINUE
            WRITE(6,850)
       850  FORMAT(' ',' ENTER BEG. YEAR, IF IT IS A LEAP YEAR(YES=1',
           *' ,0=0),'/' DATA TYPE (METRIC=1, NONMETRIC=0)'/)
            READ(5,851) IYR,ILEAP,IDTYPE
       851  FORMAT(I4,2I1)
      C----
      C---- OPTION FOR DAILY OUTPUT OR PHENO. STAGE PREDICTION
      C----
            WRITE(6,26)
        26  FORMAT(' ',' ENTER OPTION FOR DAILY OUTPUT OR PHENO.',
           *' PREDICTION TABLES'/' (DAILY OUTPUT ONLY=1,PHENO OUTPUT ONLY=0,',
           *' OR BOTH=2)'/)
            READ(5,710) IDOP
       710  FORMAT(I1)
      C----
      C---- INPUT SPECIE AND CARDINAL TEMPS.
      C----
            WRITE(6,25)
        25  FORMAT(' ',' ENTER SPECIE NAME AND NUMBER, ALSO CARDINAL',
           *' TEMPS. IN A A6,A12 FORMAT'/)
            READ(5,27) SP,ISP,TL,TO,TU
        27  FORMAT(A6,I2,3F2.0)
            IF (ISP.EQ.0) GO TO 9999
        23  WRITE(6,854)
       854  FORMAT(' ',' ENTER CONSTANT FOR CALC. OF STRESS FACTOR'/)
            READ(5,855) CONST
       855  FORMAT(F5.3)
            WRITE(6,852)
       852  FORMAT(' ',' IS SOIL MOISTURE OR ATMOSPHERIC STRESS TO BE',
           *'/' CALCULATED AND APPLIED(ANS. EACH WITH YES=1, NO=0)'/)
            READ(5,853) NOSW,NOATM
       853  FORMAT(2I1)
            NDT=456
            IF (ILEAP.EQ.1) NDT=457
      C----
```

```
C----      OVERRIDE SOIL MOIST, IF NECESSARY
C----
      IDAY=0
      WRITE(6,400)
  400 FORMAT(' ',' DO YOU WANT TO INPUT NEW SOIL MOISTURE VALUE',
     *' FOR BEGINNING'/' OF CALC.?(YES=1,NO=0) IF NO, THE CALC.',
     *' WILL START'/' AT THE TIME SNOW IS OFF & WITH H2O CONTENT',
     *' AT F.C.'/)
       READ(5,720) IQ
  720  FORMAT(I1)
       IF(IQ.EQ.0)GO TO 410
       WRITE(6,420)
  420  FORMAT(/,5X,'INPUT AS DAY # AND THEN THE DECIMAL(0 TO 1.0)',
     *' OF AVAILABLE WATER IN THE WHOLE PROFILE'/)
       READ(5,730) IDAY,SMO
  730  FORMAT(I3,F3.2)
  410  CONTINUE
C----
C----      READ NORMAL TEMPS
C----
      J=1
      IU=8
   37 CONTINUE
      K=J+4
      IF (IOTYPE.EQ.0) READ(IU,38,END=2002)
     *((XNT(L,N),N=1,2),XNP(L),L=J,K)
      IF (IOTYPE.NE.0) READ(IU,39,END=2002)
     *((XNT(L,N),N=1,2),XNP(L),L=J,K)
   38 FORMAT(15X,5(2F4.1,F4.2))
   39 FORMAT(15X,5(2F4.1,F4.3))
   36  J=J+5
       IF (J.GT.NDT) GO TO 2003
       GO TO 37
 2002   NDT=L-1
 2003   CONTINUE
        IF(IOTYPE.EQ.0) GO TO 43
         DO 41 IX=1,NDT
         XNP(IX)=XNP(IX)/10.
   41    CONTINUE
         GO TO 44
   43    DO 42 IX=1,NDT
          XNP(IX)=XNP(IX)*2.54
   42    CONTINUE
   44   CONTINUE
C----
C---- INPUT ACTUAL TEMPS AND PRECIP
C----
       WRITE(6,80)
    80 FORMAT(' ',' DO YOU HAVE ANY ACTUAL TEMPS & PRECIP TO INPUT',
     *' (YES=1,NO=0)'/' IF YES THEN ENTER FIRST & LAST DAY NUMBERS!/)
       READ(5,82) IC,IF,IL
    82 FORMAT(I1,2I3)
       IF (IC.EQ.0) NEWTEM=0
       IF (IC.EQ.0) GO TO 302
       NEWTEM=1
       WRITE(6,84)
    84 FORMAT(' ',' ENTER VALUES- TMX,TMN,PRECIP -(EACH',
     *' ONE 4 COLS. WITHOUT A DECIMAL POINT)<CR>'/)
       DO 89 L=IF,IL
       IF (IOTYPE.EQ.0) GO TO 85
        READ(5,87)(XNT(L,K),K=1,2),XNP(L)
```

```
      GO TO 89
   85 READ(5,86)(XNT(L,K),K=1,2),XNP(L)                                  00012200
   86 FORMAT(2F4.1,F4.2)                                                 00012300
   87 FORMAT(2F4.1,F4.3)                                                 00012400
   89 CONTINUE                                                           00012500
      IF (IDTYPE.EQ.0) N=130                                             00012600
      IF (IDTYPE.NE.0) N=135                                             00012700
      DO 150 J=1,NDT,5                                                   00012800
      DO 170 M=J,J+4                                                     00012900
      GO TO N                                                            00013000
  135 IXNP(M)=XNP(M)*1000.                                               00013100
      GO TO 140                                                          00013200
  130 IXNP(M)=XNP(M)*100.                                                00013300
  140 DO 170 LN=1,2                                                      00013400
  170 IXNT(M,LN)=XNT(M,LN)*10.                                           00013500
      WRITE(IU,160)((IXNT(L,K),K=1,2),I),IXNP(L),L=J,J+4)                00013600
  160 FORMAT(16X,15I4)                                                   00013700
  150 CONTINUE                                                           00013800
      LOCK IU                                                            00013900
  302 CONTINUE                                                           00014000
      IU=13                                                              00014100
  200 CONTINUE                                                           00014200
  300 CONTINUE                                                           00014300
C---- ------------------------------------------------------------------ 00014400
C---- INPUT DATE SNOW OFF                                                00014500
C---- ------------------------------------------------------------------ 00014600
      WRITE(6,60)                                                        00014700
   60 FORMAT(' ',' INPUT DAY # SNOW IS OFF THE SITE, AND',               00014800
     *1 ' THE NUMBER OF DAYS IN THE'/' GROWING SEASON FOR THE',          00014900
     *1 ' SITE'/)                                                        00015000
      READ(5,859) ISNOW,NDAYS                                            00015100
  859 FORMAT(2I3)                                                        00015200
   61 CALL MOIST(IDAY,SMO,NDT,IDTYPE,ILEAP,ISNOW,NDAYS)                  00015300
C---- ------------------------------------------------------------------ 00015400
C---- CALC. GDH FOR NEW TEMPS.                                           00015500
C---- ------------------------------------------------------------------ 00015600
      CALL GDH(IF,IL,TL,TO,TU,CONST,NOSM,NOATH,IYB,ILEAP,NDT,IDOP,       00015700
     *IDTYPE)                                                            00015800
  300 CONTINUE                                                           00015900
  600 CONTINUE                                                           00016000
  100 CONTINUE                                                           00016100
  120 CONTINUE                                                           00016200
   81 CONTINUE                                                           00016300
C---- ------------------------------------------------------------------ 00016400
C---- PREDICT PHENOLOGICAL DEVELOPMENT AND HTS OF SPECIE SELECTED        00016500
C---- ------------------------------------------------------------------ 00016600
      IF ((IDOP.EQ.0).OR.(IDOP.EQ.2))                                    00016700
     *CALL PHENO(ISP)                                                    00016800
      LOCK 8                                                             00016900
      LOCK 13                                                            00017000
      GO TO 20                                                           00017100
 9999 CONTINUE                                                           00017200
      STOP                                                               00017300
      END                                                                00017400
      SUBROUTINE MOIST(IDAY,SMO,NDT,IDTYPE,ILEAP,ISNOW,NDAYS)            00017500
C---- ------------------------------------------------------------------ 00017600
C---- SUBROUT. TO CALC. SOIL MOIST BUDGETS (EQIV, DEPTHS)                00017700
C---- VIA ET AND PCPN (AFTER HANKS 1974)                                 00017800
C---- ------------------------------------------------------------------ 00017900
      COMMON /BLK1/ XNP(475),XNT(475,2),ETT(475),EA(475)                 00018000
      COMMON /BLK3/ AA(475),TRAT(4)                                      00018100
```

```
      DIMENSION PSM(500),LOM(15)                                        00018200
C---- SET LAST DAY NUMBERS OF MONTHS                                    00018300
C---- SET LAST DAY NUMBERS OF MONTHS                                    00018400
      DATA LOM/30,61,91,122,153,181,212,242,273,303,334,365,            00018500
     *395,426,456/                                                      00018600
C---- THRESHOLD LEVEL FOR EVAP. ALGORITHM                               00018700
C---- THRESHOLD LEVEL FOR EVAP. ALGORITHM                               00018800
C---- SET WATER CON. FOR FIRST DAY EQUAL TO FIELD CAP.                  00018900
      DATA FC,WP/127.,55./, PTH/5.1/                                    00019000
      WCSET=FC                                                          00019100
      XMNTH=1.0                                                         00019200
      IF (ILFAP.EQ.0) GO TO 10                                          00019250
      DO 5 I=6,15                                                       00019300
      LOM(I)=LOM(I)+1.                                                  00019400
    5 CONTINUE                                                          00019500
   10 CONTINUE                                                          00019600
C---- SET WATER CON. FOR FIRST DAY EQUAL TO FIELD CAP.                  00019700
C---- SET WATER CON. FOR FIRST DAY EQUAL TO FIELD CAP.                  00019800
C---- INPUT NEW SOIL MOIST IF NEC.                                      00019900
      BSM=WP                                                            00020000
C---- INPUT NEW SOIL MOIST IF NEC.                                      00020100
C---- INPUT NEW SOIL MOIST IF NEC.                                      00020200
      IF(IDAY.EQ.0)GO TO 400                                            00020300
      PSM(IDAY)=(SMO*(FC-WP))+WP                                        00020400
      BSM=PSM(IDAY)                                                     00020500
      GO TO 400                                                         00020600
      WRITE(6,410)                                                      00020700
  410 FORMAT(//,5X,'UPDATE DATE IS POST DATE OF PEAK PRODN, THUS'       00020800
     */' PROD EST, BASED UPON TRANS RATIO OF THE UPDATE DATE'/)         00020900
  400 CONTINUE                                                          00021000
C---- BEGIN DLY BUDGETTING OF SOIL WATER                                00021100
C---- BEGIN DLY BUDGETTING OF SOIL WATER                                00021200
      DO 97 MN=1,4                                                      00021300
   97 TRAT(MN)=0.0                                                      00021400
      SS=0.                                                             00021500
      S6=0.                                                             00021600
      DO 60 J=1,INDT                                                    00021700
      IF (J.EQ.182) BSM=FC/2.                                           00021800
C---- DET TIME SINCE LAST PCPN GT. PTH FOR EVAP. ESTIMATION             00021900
C---- DET TIME SINCE LAST PCPN GT. PTH FOR EVAP. ESTIMATION             00022000
      TIME=10.                                                          00022050
      II=10                                                             00022100
      IF (J.EQ.1) GO TO 63                                              00022200
      IF ((J.LE.10).AND.(J.GT.1)) II=J-1                                00022300
      DO 61 LL=1,II                                                     00022400
      IL=LL-1                                                           00022500
      IF (LL.EQ.1) PCPN=XNP(J-IL)                                       00022600
      IF (LL.GT.1) PCPN=XNP(J-IL)-XNP(J-LL)                             00022700
      IF(PCPN.GT.PTH)TIME=LL                                            00022800
      IF(PCPN.GT.PTH)GO TO 63                                           00022900
   61 CONTINUE                                                          00023000
   63 CONTINUE                                                          00023100
C---- DETERMINE MONTH                                                   00023200
C---- DETERMINE MONTH                                                   00023300
      DO 110 II=1,14                                                    00023400
      IF(J.GE.LOM(II).AND.J.LT.LOM(II+1))GO TO 120                      00023500
```

```
24100      110 CONTINUE                                                        00024100
24200       120 IM=II                                                          00024200
24300      C----                                                               00024300
24400      C----CALC, POT ET FOR PERIOD                                        00024400
24500      C----                                                               00024500
24600            CALL TE(J,IM)                                                00024600
24800      C----                                                               00024800
24900      C---- CALC, ACTUAL ET                                               00024900
25000      C----                                                               00025000
25100            CALL ETSEP(BSM,W,TIME,TA,TP,EP,J,ISNOW,NDAYS)                00025100
25150              IF (J.GT.181) GO TO 64                                     00025150
25160               EA(J)=0.0                                                 00025160
25170               GO TO 70                                                  00025170
25175        64    IF (J.EQ.182) ETT(J)=0.0                                   00025175
25200              AW(J)=W                                                    00025200
25300            S5=S5+TA                                                     00025300
25400            S6=S6+TP                                                     00025400
25500              IF(S6.EQ.0.)S6=1.                                          00025500
25600      C----                                                               00025600
25700      C----CALCULATE PRECIPITATION FOR PERIOD                             00025700
25800      C----                                                               00025800
25900              IF (J.EQ.1) SP=XNP(J)                                      00025900
26000              IF (J.GT.1) SP=XNP(J)+XNP(J-1)                             00026000
26050               IF (SP.LT.0.0) SP=0.0                                     00026050
26100      C----                                                               00026100
26200      C---- PREDICT SOIL MOIST AND ADJUST FOR PWP AND FC.                 00026200
26300      C----                                                               00026300
26400            PSM(J)=BSM+EA(J)-TA+SP                                       00026400
26500            IF (PSM(J).GT.FC) PSM(J)=FC                                 00026500
26600            IF (PSM(J).LT.WP) PSM(J)=WP                                 00026600
26700            BSM=PSM(J)                                                  00026700
26800            GO TO 60                                                    00026800
26900        70   IF (J.EQ.1) SP=XNP(J)                                      00026900
27000              IF (J.GT.1) SP=XNP(J)+XNP(J-1)                             00027000
27025               IF (SP.LT.0.0) SP=0.0                                     00027025
27050              AW(J)=W                                                    00027050
27100              PSM(J)=BSM+SP                                              00027100
27200            BSM=PSM(J)                                                  00027200
27300            EA(J)=0.0                                                   00027300
27400        60 CONTINUE                                                     00027400
27500              RETURN                                                    00027500
27600            END                                                         00027600
27700            SUBROUTINE TE(LLD,IM)                                       00027700
27800            COMMON /BLK1/ XNP(475),XNT(475,2),ETT(475),EA(475)          00027800
27900            DIMENSION PD(15), XNDS(15)                                  00027900
28000      C----                                                               00028000
28100      C---- SET X OF DAY LIGHT HOURS PER MONTH                           00028100
28200      C----                                                               00028200
28300            DATA PD/8.38,7.75,6.72,6.52,6.76,6.73,8.33,8.95,10.02,      00028300
28400           *10.08,10.22,9.54,8.38,7.75,6.72/                            00028400
28500      C----                                                               00028500
28600      C----SET THE NUMBER OF DAYS PER MONTH                               00028600
28700      C----                                                               00028700
28800            DATA XNDS/30,31,30,31,31,28,31,30,31,30,31,31,30,31,30/     00028800
28900      C----                                                               00028900
29000      C---- CALC, AVERAGE TEMP.                                          00029000
29100      C----                                                               00029100
29200            IF (TOTYPE.EQ.0) GO TO 15                                   00029200
29300            TA=(((XNT(LLD,1)+XNT(LLD,2))/2.)*(9./5.))+32.               00029300
29400            GO TO 20                                                    00029400
29500       15   TA=(XNT(LLD,1)+XNT(LLD,2))/2.                               00029500
```

```
29600      20  E=(((TA)*PD(IM))/(100*XNDS(IM)))                          00029600
29700       10 CONTINUE                                                  00029700
29800          ETT(LLD)=E*25.4                                          00029800
29900          RETURN                                                   00029900
30000          END                                                      00030000
30100          SUBROUTINE ETSEP(BSM,W,TIME,TA,TP,EP,LLD,ISNOW,NDAYS)    00030100
30200  C----                                                            00030200
30300  C----CALC. EA AND TA SEPARATELY FROM HANKS (1974)                00030300
30400  C----                                                            00030400
30500          COMMON /BLK1/ XNP(475),XNT(475,2),ETT(475),EA(475)       00030500
30600          COMMON /BLK3/ AX(475),TRAT(4)                            00030600
30700          DIMENSION CO(5)                                          00030700
30800  C----                                                            00030800
30900  C----   SET COEFFS. OF EQN. OF EVAP. FACTOR VS TENTHS OF GROW. SEASON  00030900
31000  C----                                                            00031000
31100          DATA CO/100.,-26.62,-.652,.645,-.0399/                   00031100
31200          DATA FC,WP/127.,55./                                     00031200
31300  C----                                                            00031300
31400  C----      CALC. FRATION OF GROW. SEASON COMPLETED AS OF TODAY    00031400
31500  C----                                                            00031500
31600           X=LLD                                                   00031600
31700          Y=ISNOW                                                  00031700
31800          Z=NDAYS                                                  00031800
31900           FRAC=(X-Y)/Z                                            00031900
32000          IF(FRAC.GT.1.)FRAC=1.                                    00032000
32100            IF(FRAC.LT.0.)FRAC=0.                                  00032100
32200          FRAC=FRAC*10.                                            00032200
32300  C----                                                            00032300
32400  C----   CALC. WHAT % OF TOTAL ETP COULD GO TO POT. EVAP.         00032400
32500  C----                                                            00032500
32600          FEP=CO(1)+CO(2)*FRAC+CO(3)*FRAC**2.+CO(4)*FRAC**3.+CO(5) 00032600
32700       **FRAC**4.                                                  00032700
32800           IF(FEP.GT.100.)FEP=100.                                 00032800
32900          IF(FEP.LT.0.)FEP=0.                                      00032900
33000          EP=((FEP*.01)*ETT(LLD))                                  00033000
33100  C----                                                            00033100
33200  C----  CALC. ACTUAL EVAP.                                       00033200
33300  C----                                                            00033300
33400          EA(LLD)=EP*(SQRT(1/TIME))                                00033400
33500  C----                                                            00033500
33600  C----   CALC. POTENTIAL TRANS.                                   00033600
33700  C----                                                            00033700
33800          TP=ETT(LLD)-EP                                           00033800
33900          BB=BSM                                                   00033900
34000          IF (BB.GT.FC) BB=FC                                      00034000
34100          IF (BB.LT.WP) BB=WP                                      00034100
34200  C----                                                            00034200
34300  C----W IS THE PERCENT OF AVAILABLE WATER                         00034300
34400  C----                                                            00034400
34500          W=1.-((FC-BB)/(FC-WP))                                   00034500
34600  C----                                                            00034600
34700  C----CALCULATE ACTUAL TRANSPIRTATION                             00034700
34800  C----                                                            00034800
34900          TA=TP*W**2.                                              00034900
35000          IF(TA.GT.TP)TA=TP                                        00035000
35100          RETURN                                                   00035100
35200          END                                                      00035200
35300          SUBROUTINE PHEND(NSPECE)                                 00035300
35400           COMMON /BLK2/ NG(475),SPK(2,10),NDGDH(475)              00035400
35500          DIMENSION ACGDH(6,8),HGHTS(6,8),BIOMAS(6,8),             00035500
35600         A(6,8),I)                                                 00035600
```

```
      DATA ACGDH/0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,2880.0,
     *0.0,0.0,2773.0,3228.0,
     *5030.0,5152.0,3925.0,7343.0,5368.0,6337.0,6425.0,
     *6309.0,7006.0,11621.0,7500.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,
     *0.0,10184.0,9188.0,9571.0,9927.0,21053.0,13120.0,
     *11034.0,11622.0,12802.0,11716.0,23988.0,25376.0,
     *12675.0,12675.0,16933.0,14402.0,26080.0,27700.0/
      DATA MGHTS/0.0,2100.0,1100.0,2600.0,0.0,0.0,0.0,0.0,
     *4400.0,2500.0,5900.0,0.0,0.0,0.0,0.0,7700.0,3700.0,
     *9700.0,0.0,0.0,0.0,0.0,0.0,0.0,5000.0,5.0,0.0,0.0,0.0,0.0,0.0,
     *6700.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,9200.0,0.0,0.0,0.0,0.0,0.0,0.0,
     *0.0,11300.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0,0.0/
      DATA BIOMAS/2100.0,1800.0,1300.0,4800.0,0.0,0.0,0.0,0.0,
     *1900.0,3400.0,2700.0,6600.0,0.0,0.0,0.0,0.0,5400.0,4600.0,
     *4300.0,11300.0,0.0,0.0,0.0,0.0,6600.0,5600.0,6200.0,
     *13200.0,0.0,0.0,0.0,0.0,7700.0,6500.0,8500.0,0.0,0.0,0.0,0.0,0.0,
     *8600.0,7200.0,11400.0,0.0,0.0,0.0,0.0,0.0,0.0,9400.0,7900.0,
     *10700.0,0.0,0.0,0.0,0.0,10100.0,8500.0,0.0,0.0,0.0,0.0,0.0,0.0/
      DO 20 I=123,304
       DO 10 J=1,5
        IDATE=I+J-1
        IF (NDGDH(IDATE),LT,1) GO TO 20
 10    CONTINUE
       IBEG=I
       GO TO 25
 20   CONTINUE
 25   NSTAGE=1
      DO 50 I=IBEG,457
       NETGDH=NG(I)-NG(IBEG)
       IF (NSTAGE,GT,8) GO TO 55
 27    IF (ACGDH(NSPECE,NSTAGE),EQ,0.0) GO TO 35
       IF (NETGDH,GE,ACGDH(NSPECE,NSTAGE)) GO TO 40
       GO TO 50
 35    NSTAGE=NSTAGE+1
       IF (NSTAGE,GE,8) GO TO 55
       GO TO 27
 40    IDAY(1,NSTAGE)=I
       NSTAGE=NSTAGE+1
 50    CONTINUE
 55    NSTAGE=1
      DO 70 I=IBEG,457
      IF (NSTAGE,GT,8) GO TO 75
 56    IF (MGHTS(NSPECE,NSTAGE),EQ,0.0) GO TO 57
        NETHTS=NG(I)-NG(IBEG)
        IF (NETHT,GE,MGHTS(NSPECE,NSTAGE)) GO TO 60
        GO TO 70
 57     NSTAGE=NSTAGE+1
        IF (NSTAGE,GE,8) GO TO 75
        GO TO 56
 60     IDAY(2,NSTAGE)=I
        NSTAGE=NSTAGE+1
 70    CONTINUE
 75    NSTAGE=1
      DO 90 I=IBEG,457
      IF (NSTAGE,GT,8) GO TO 100
 76    IF (BIOMAS(NSPECE,NSTAGE),EQ,0.0) GO TO 77
        NETBIO=NG(I)-NG(IBEG)
        IF (NETBIO,GE,BIOMAS(NSPECE,NSTAGE)) GO TO 80
       GO TO 90
 77     NSTAGE=NSTAGE+1
```

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00035650
00035700
00035750
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00035900
00035950
00036000
00036050
00036100
00036150
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39744          GO TO 76                                                  00039744
39745    80    IDAY(3,NSTAGE)=I                                          00039745
39750          NSTAGE=NSTAGE+1                                           00039750
39755    90    CONTINUE                                                  00039755
39760   100    WRITE(7,110)(IDAY(1,J),J=1,8)                             00039760
39765   110    FORMAT(" ",8X,"DAY # OF PHENOL. STAGE DEVEL.*/,           00039765
     *"      1     2     3     4     5     6     7     8"/3X,I3,7(2X,I3))00039770
39775          WRITE(7,120)(IDAY(2,J),J=1,8)                             00039775
39780   120    FORMAT(" ",8X,"DAY # OF HEIGHT LEVELS (CM)"/,             00039780
     *"      5    10    15    20    25    30    35    40"/3X,I3,7(2X,I3))00039785
39790          WRITE(7,130)(IDAY(3,J),J=1,8)                             00039790
39795   130    FORMAT(" ",8X,"DAY # OF BIOMASS DEVEL. (GMS)"/,           00039795
     *"      5    10    15    20    25    30    35    40"/3X,I3,7(2X,I3))00039800
39805          RETURN                                                    00039805
39810          END                                                       00039810
39815          SUBROUTINE GDM(IF,IL,TL,TD,TU,CONST,NOSM,NDATH,IYB,       00039815
39820         *ILEAP,NDT,IDOP,IDTYPE)                                    00039820
39825          COMMON /BLK1/ XNP(475),XNT(475,2),ETT(475),EA(475)        00039825
39830           COMMON /BLK2/ NG(475),SPK(2,10),NDGDH(475)               00039830
39835          COMMON /BLK3/ AM(475),TRAT(4)                             00039835
39840          DIMENSION NDS(15),XMM(15)                                 00039840
39845          DIMENSION TH(24),RH(24)                                   00039845
39850          DATA XCTM/0.25/,YINT/0.5/                                 00039850
39900          DATA NDS/30,31,30,31,31,28,31,30,31,30,31,31,30,31,30,30/ 00039900
40000          DATA XMM/'SEP','OCT','NOV',1DEC',1JAN',1FEB',1MAR',1APR',  00040000
     *'MAY','JUN','JUL','AUG','SEP','OCT','NOV'/                        00040100
40200          DATA NP/12/,NI/2/,DTN/17.0/,DTX/22./,FX/.25/              00040200
40300  C----                                                             00040300
40400  C----                                                             00040400
40500  C---- LOOP FOR DAYS                                               00040500
40600  C----                                                             00040600
40700          IYR=IYB                                                   00040700
40800           SMGDH=0.0                                                00040800
40900          IF (ILEAP.EQ.1) NDS(6)=29                                 00040900
41000          NDN=NDS(1)                                                00041000
41100          IYE=IYB+1                                                 00041100
41200          JH=1                                                      00041200
41300          DO 20 I=I,NDT                                             00041300
41400          IF (IDTYPE.NE.0) GO TO 801                                00041400
41500          XNT(I,1)=(XNT(I,1)-32.)*(5./9.)                           00041500
41600          XNT(I,2)=(XNT(I,2)-32.)*(5./9.)                           00041600
41700      801 TAVE=(XNT(I,1)+XNT(I,2))*0.5                              00041700
41800          IF (I.EQ.1) GO TO 23                                      00041800
41900          T1=XNT(I-1,2)                                             00041900
42000          GO TO 24                                                  00042000
42100       23 T1=XNT(I,2)                                               00042100
42200       24 T2=XNT(I,1)                                               00042200
42300          T3=XNT(I,2)                                               00042300
42400  C----                                                             00042400
42500  C----  CALC. HRLY TEMPS.                                          00042500
42600  C----                                                             00042600
42700          K=I                                                       00042700
42800          NH=NP                                                     00042800
42900          XXNP=NP                                                   00042900
43000          II=1                                                      00043000
43100       70 DO 50 J=II,NH                                             00043100
43200          Z=J                                                       00043200
43300          IF(K.EQ.2)Z=J-NP                                          00043300
43400          FC=(Z-1.)/(XXNP-1.)                                       00043400
43500          TH(J)=T2-((T2-T1)*FC)                                     00043500
43600          RH(J)=1.0                                                 00043600
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      IF (TH(J).LT.THI) GO TO 50                                        00043700
      DT=TH(J)-T1                                                       00043800
      IF (DT.GE.DTX) RH(J)=FX                                           00043900
      IF ((DT.GE.0).AND.(DT.LE.DTX)) GO TO 50                           00044000
      RH(J)=1.55*((1.0-FX)/(DTX-DTX))*DT)                               00044100
      RH(J)=1.55*((1.0-FX)/(DTN-DTX))*DT)                               00044200
   50 CONTINUE                                                          00044300
      IF(K.NE.1)GO TO 60                                                00044400
      I1=NP+1                                                           00044500
      NM=24                                                             00044600
      XXNP=24-NP                                                        00044700
      K=2                                                               00044800
      T1=T3                                                             00044900
      GO TO 70                                                          00045000
   60 CONTINUE                                                          00045100
  205 CONTINUE                                                          00045200
C----                                                                   00045300
C---- CALC. GDH FOR DAY                                                 00045400
C----                                                                   00045500
      L=1                                                               00045600
       GD=0.0                                                           00045700
      DO 21 K=1,24                                                      00045800
      FSM=1.0                                                           00045900
      FACT=1.0                                                          00046000
      A=TO-TL                                                           00046100
       IF ((JM.GE.1).AND.(JM.LE.5)) GO TO 30                            00046200
      IF (NOSW.EQ.0) GO TO 10                                           00046300
      IF (AW(I).GT.WCTH) GO TO 30                                       00046400
      FSM=YINT+(((1.0-YINT)/WCTH)*AW(I))                                00046500
   10 IF (NOATM.EQ.0) GO TO 15                                          00046600
      IF (RH(K).GT.TL) GO TO 30                                         00046700
      A=A+((FSM*RH(K))/CONST)                                           00046800
      GO TO 30                                                          00046900
   15 A=A+FSM                                                           00047000
   30 CONTINUE                                                          00047100
      TN=TH(K)                                                          00047200
      IF (TN.LT.TL) TN=TL                                               00047300
      IF (TN.GT.TU) TN=TU                                               00047400
      IF (TN.GE.TO) GO TO 400                                           00047500
      DGD=(A/2.)*(1+COS(3.14159+(3.14159*((TN-TL)/(TO-TL)))))           00047600
      GO TO 401                                                         00047700
  400 DGD=(A)*(1+COS((3.14159/2.)+((3.14159/2.)*((TN-TO)/(TU-TO)))))    00047800
  401 GD=GD+DGD                                                         00047900
   21     CONTINUE                                                     00048000
      SMGDH=SMGDH+GD                                                    00048100
      NGI(1)=SMGDH                                                      00048150
       NDGDH(I)=GD                                                      00048200
       IF (I.LE.NDM) GO TO 6                                            00048300
       JM=JM+1                                                          00048400
      NDM=NDM+NDS(JM)                                                   00048500
    6 IF (I.EQ.123) IYR=IYE                                             00048600
      IDC=I-1.0*NDS(JM)                                                 00048700
       IF (I.NE.1) GO TO 498                                            00048800
       IF ((IDOP.EQ.1).OR.(IDOP.EQ.2)) WRITE(7,499)                     00048900
  499 FORMAT(' ',18X,'TEMPERATURE',6X,'HEAT UNITS',6X,'EVAPORA',       00049000
     *'TION UNITS',/1X,'DAY   DATE      TMX      TMN   TAVE   GDH      SM',00049100
     *'GDH  PRECIP      ETT     EA      A,H20')                        00049200
  498 IF ((IDOP.EQ.1).OR.(IDOP.EQ.2)) WRITE(7,500)                      00049300
     *I,IDC,XMN(JM),IYR,(XNT(I,L),L=1,2),TAVE,GD,SMGDH,XNP(I),ETT(I),   00049400
     *EA(I),A(I)                                                        00049500
  500 FORMAT(' ',I4,I3,A3,I4,2F6.1,F6.2,F7.2,F9.1,1X,F5.3,3F9.4)       00049600
   20 CONTINUE                                                          00049700
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49700          RETURN                                    00049700
49800          END                                       00049800
49900    2                                               00049900
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